Time of Concentration and Travel Time

Travel time (T_t) is the time it takes water to travel from one location to another in a watershed. T_t is a component of time of concentration (T_c) which is the time for runoff to travel from the hydraulically most distant point of the watershed to a point of interest within the watershed. T_c is computed by summing all the travel times for consecutive components of the drainage conveyance system.

T_c influences the shape and the peak of the runoff hydrograph. Urbanization usually decreases T_c, thereby increasing the peak discharge. But T_c can be increased as a result of (a) ponding behind small or inadequate drainage systems, including storm drain inlets and road culverts, or (b) reduction of land slope through grading.

Factors Affecting Time of Concentration and Travel Time

Surface Roughness: One of the most significant effects of urban development on flow velocity is less retardance to flow. This is, undeveloped areas with very slow and shallow overland flow through vegetation become modified by urban development: the flow is then delivered to streets, gutters, and storm sewers that transport runoff downstream more rapidly. Travel time through the watershed is generally decreased.

Channel Shape and Flow Patterns: In small non—urban watersheds, much of the travel time results from overland flow in upstream areas. Typically, urbanization reduces overland flow lengths by conveying storm runoff into a channel as soon as possible. Since designed channels have efficient hydraulic characteristics, runoff flow velocity increases and travel time decreases.

Slope: Slopes may be increased or decreased by urbanization, depending on the extent of site grading or the extent to which storm sewers and street ditches are used in the design of the water management system. Slope will tend to increase when channels are straightened and decrease when overland flow is directed through storm sewers, street gutters, and diversions.

Computation of Travel Time and Time of Concentration

Water moves through a watershed as sheet flow, shallow concentrated flow, open channel flow, or some combination of these. The type that occurs is a function of the conveyance system and is best determined by field inspection.

Travel time (T_t) is the ratio of flow length to flow velocity:

$$T_t = \frac{L}{3600\ V} \qquad \text{[Eq. B—5]}$$

where

T_t = travel time (hr),

L = flow length (ft),

V = average velocity (ft/s), and

3600 = conversion factor from seconds to hours

Time of concentration (T_c) is the sum of T_t values for the various consecutive flow segments:

$$T_c = T_{t1} + T_{t2} + \ldots T_{tm} \qquad \text{[Eq. B—6]}$$

where

T_c = time of concentration (hr) and

m = number of flow segments.

Sheet Flow: Sheet flow is flow over plane surfaces. It usually occurs in the headwater of streams. With sheet flow, the friction value (Manning's n) is an effective roughness coefficient that includes the effect of raindrop impact; drag over the plane surface; obstacles such as litter, crop ridges, and rocks; and erosion and transportation of sediment. These n values are for very shallow flow depths of about 0.1 foot or so. Table B—4 gives Manning's n values for sheet flow for various surface conditions.

For sheet flow of less than 300 feet, use Manning's kinematic solution to compute T_t:

$$T_t = \frac{0.007\,(nL)^{0.8}}{(P_2)^{0.5}\,(S)^{0.4}} \qquad \text{[Eq. B—7]}$$

where

T_t = travel time (hr),

n = Manning's roughness coefficient, Table B—4

L = flow length (ft),

P_2 = 2—year, 24—hour rainfall (in), and

s = slope of hydraulic grade line (land slope, ft/ft).

This simplified form of Manning's kinematic solution is based on the following:

(1) shallow steady uniform flow,

(2) constant intensity of rainfall excess (that part of a rain available for runoff),

(3) rainfall duration of 24 hours, and

(4) minor effect of infiltration on travel time.

Rainfall depth can be obtained from Exhibit B—1.

TABLE B-4 — Roughness Coefficients

(MANNING'S n) for Sheet Flow	
Surface Description	n^1
Smooth surfaces (concrete, asphalt, gravel or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover <20%	0.06
Residue cover >20%	0.17
Grass:	
Short grass prarie	0.15
Dense grasses[2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods:[3]	
Light underbrush	0.40
Dense underbrush	0.80

[1]The values are a composite of information compiled by Engman (1980)
[2]Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
[3]When selecting n consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

Shallow Concentrated Flow; After a maximum of 300 feet, sheet flow usually becomes shallow concentrated flow. The average velocity for this flow can be determined from Figure B—10 in which average velocity is a function of watercourse slope and type of channel. tillage can affect the direction of shallow concentrated flow. Flow may not always be directly down the watershed slope if tillage runs across the slope.

After determining velocity in Figure B—10, use equation B—5 to estimate travel time for the shallow concentrated flow segment.

Open Channels: Open channels are assumed to begin where surveyed cross section information has been obtained, where channels are visible on aerial photographs, or where blue lines (indicating streams) appear on United States Geological Survey (USGS) quadrangle sheets. Manning's equation or water surface profile information can be used to estimate average flow velocity. Average flow velocity is usually determined for bank—full elevation.

Manning's equation is

$$V = \frac{1.49\, r^{2/3}\, s^{1/2}}{n} \qquad \text{[Eq. B—8]}$$

where

V = average velocity (ft/sec),

r = hydraulic radius (ft) and is equal to a/Pw,

a = cross sectional flow area (ft^2),

Pw = wetted perimeter (ft),

s = slope of the hydraulic grade line (channel slope, ft/ft), and

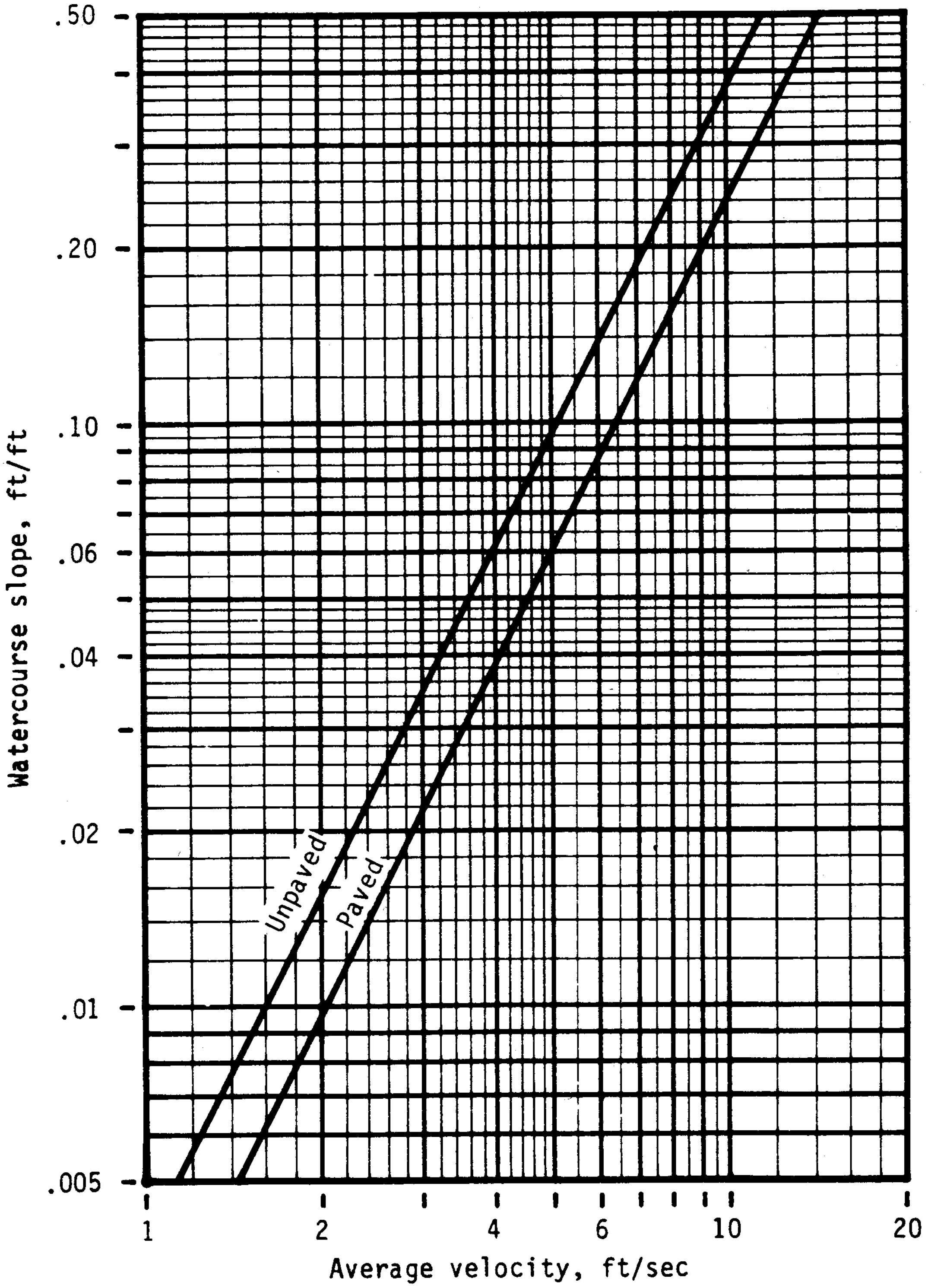
n = Manning's roughness coefficient for open channel flow.

Manning's "n" values for open channel flow can be obtained from standard textbooks. After average velocity is computed using equation B—8, T_t for the channel segment can be estimated using equation B—5.

Figure B-10

Average Velocities for Estimating Travel Time for Shallow Concentrated Flow

(Reprinted from 210-VI-TR-55, Second Ed., June 1986)



Reservoirs or Lakes: Sometimes it is necessary to estimate the velocity of flow through a reservoir or lake at the outlet of a watershed to determine travel time. This travel time is normally very small and can be assumed as zero.

Limitations: Manning's kinematic solution should not be used for sheet flow longer than 300 feet.

In watersheds with storm sewers, carefully identify the appropriate hydraulic flow path to estimate T_c. Storm sewers generally handle only a small portion of a large event. The rest of the peak flow travels by streets, lawns, and so on, to the outlet. Consult a standard hydraulics textbook to determine average velocity in pipes for either pressure or non—pressure flow.

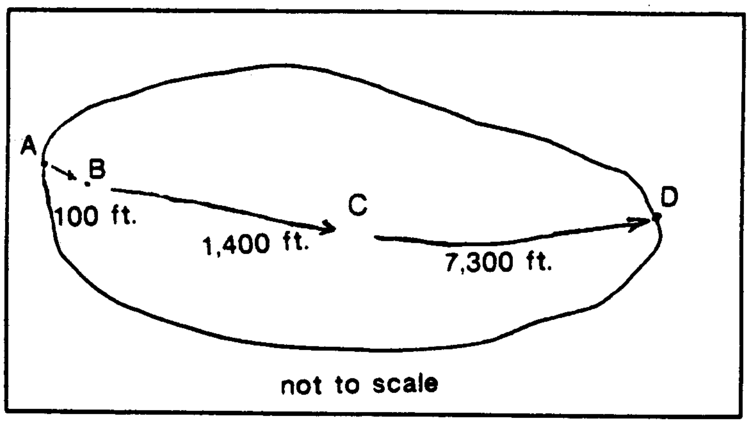
The minimum T_c used is 0.1 hour.

A culvert or bridge can act as a reservoir outlet if there is significant storage behind it. The procedures in TR—55 can be used to determine the peak flow upstream of the culvert. Detailed storage routing procedures should be used to determine the outlet through the culvert.

Figure B—11 provides Worksheet 3 for calculating Time of Concentration (T_c) or travel time (T_t).

Example 5:
The sketch below shows a watershed in Marion County, West Virginia. The problem is to compute T_c at the outlet of the watershed (point D). The 2—year 24—hour rainfall depth is 2.65 inches.

All three types of flow occur from the hydraulically most distant point (A) to the point of interest (D). To compute T_c, first determine T_t for each segment from the following information:



Segment AB: Sheet flow; dense grass; slope (s) = 0.01 ft/ft: and length (L) = 100 ft.

Segment BC: Shallow concentrated flow; unpaved; s = 0.01 ft/ft; and L = 1400 ft.

Segment CD: Channel flow; Manning's n = .05; flow area (a) = 27 ft^2; wetted perimeter (pw) = 28.2 ft;s = 0.005 ft/ft; and L = 7300 ft.

See Figure B—12 for the computations made on Worksheet 3 for Example 5.

Graphical Peak Discharge Method

The Graphical method was developed from hydrograph analyses using TR—20, "Computer Program for Project Formulation—Hydrology". The peak discharge equation used is:

$$qp = qu\,A_m\,Q\,F_p \qquad \text{[Eq. B—9]}$$

where

qp = peak discharge (cfs);

qu = unit peak discharge (csm/in);

A_m = drainage area (mi^2);

Q = runoff (in); and

F_p = pond and swamp adjustment factor.

The input requirements for the Graphical method are as follows:

(1) T_c (hr),
(2) drainage area (mi^2),
(3) 24—hour rainfall (in), and
(4) CN.

If pond and swamp areas are spread throughout the watershed and are not considered in the T_c computation, an adjustment for pond and swamp areas is also needed.

Peak Discharge Computation

For a selected rainfall frequency, the 24—hour rainfall (P) is obtained from Exhibit B—1. CN and total runoff (Q) for the watershed were computed earlier. The CN is used to determine the initial abstraction (I_a) from Table B—5. I_a/P is then computed.

If the computed I_a/P ratio is outside the range shown in Figure B—16, then the limiting value should be used. If the ratio falls between the limiting values, use linear interpolation. Figure B—13 illustrates the sensitivity of I_a/P to CN and P.

Peak discharge per square mile per inch of runoff (qu) is obtained from Figure B—16 by using T_c and I_a/P ratio. The pond and swamp adjustment factor is obtained from Table B—6 (rounded to the nearest Table value). Use Worksheet 4, Figure B—14, to aid in computing the peak discharge using the Graphical method.

Figure B-11

Worksheet 3: Time of Concentration (T_c) or Travel Time (T_t)

(Reprinted from: 210-VI-TR-55, Second Ed., June 1986)

Project ______________________ By ______ Date __________
Location ______________________ Checked ______ Date __________
Circle one: Present Developed ______________________
Circle one: T_c T_t through subarea ______________________

Sheet flow (Applicable to T_c only) Segment ID .
1. Surface description (table B-4) ....
2. Manning's roughness coeff., n (table B-4). ....
3. Flow length, L (total L < 300 ft) .... ft
4. Two-yr 24-hr rainfall, P_2 .... in
5. Land slope, s .... ft/ft
6. $T_t = \frac{0.007\,(nL)^{0.8}}{P_2^{\,0.5}\, s^{0.4}}$ Compute T_t .... hr

Shallow concentrated flow Segment ID .
7. Surface description (paved or unpaved) ....
8. Flow length, L .... ft
9. Watercourse slope, s .... ft/ft
10. Average velocity, V (figure B-10) .... ft/s
11. $T_t = \frac{L}{3600\,V}$ Compute T_t .... hr

Channel flow Segment ID .
12. Cross sectional flow area, a .... ft^2
13. Wetted perimeter, P_w .... ft
14. Hydraulic radius, $r = \frac{a}{P_w}$ Compute r .... ft
15. Channel slope, s .... ft/ft
16. Manning's roughness coeff., n ....
17. $V = \frac{1.49\, r^{2/3}\, s^{1/2}}{n}$ Compute V .... ft/s
18. Flow length, L .... ft
19. $T_t = \frac{L}{3600\,V}$ Compute T_t .... hr
20. Watershed or subarea t_c or t_t (add t_t in steps 6, 11, and 19) .. hr

Figure B-12

Worksheet 3: Time of Concentration (T_c) or Travel Time (T_t)

Worksheet 3 for Example 5

Project Hickory Hill By SEC Date 1-7-92
Location Marion County, WV Checked ROA Date 1-7-92
Circle one: Present Developed
Circle one: T_c T_t through subarea

Sheet flow (Applicable to T_c only) Segment ID.		AB
1. Surface description (table B-4)		Dense Grass
2. Manning's roughness coeff., n (table B-4).		0.24
3. Flow length, L (total L < 300 ft)	ft	100
4. Two-yr 24-hr rainfall, P_2	in	2.65
5. Land slope, s	ft/ft	0.01
6. $T_t = \frac{0.007\,(nL)^{0.8}}{P_2^{\,0.5}\, s^{0.4}}$ Compute T_t	hr	0.34

Shallow concentrated flow Segment ID.		BC
7. Surface description (paved or unpaved)		Unpav.
8. Flow length, L	ft	1400
9. Watercourse slope, s	ft/ft	0.01
10. Average velocity, V (figure B-10)	ft/s	1.6
11. $T_t = \frac{L}{3600\,V}$ Compute T_t	hr	0.24

Channel flow Segment ID.		CD
12. Cross sectional flow area, a	ft²	27
13. Wetted perimeter, P_w	ft	28.2
14. Hydraulic radius, $r = \frac{a}{P_w}$ Compute r	ft	0.957
15. Channel slope, s	ft/ft	0.005
16. Manning's roughness coeff., n		0.05
17. $V = \frac{1.49\, r^{2/3}\, s^{1/2}}{n}$ Compute V	ft/s	2.05
18. Flow length, L	ft	7300
19. $T_t = \frac{L}{3600\,V}$ Compute T_t	hr	0.99
20. Watershed or subarea t_c or t_t (add t_t in steps 6, 11, and 19).	hr	1.57

Figure B-13 — Variation of I_a/P for P and CN

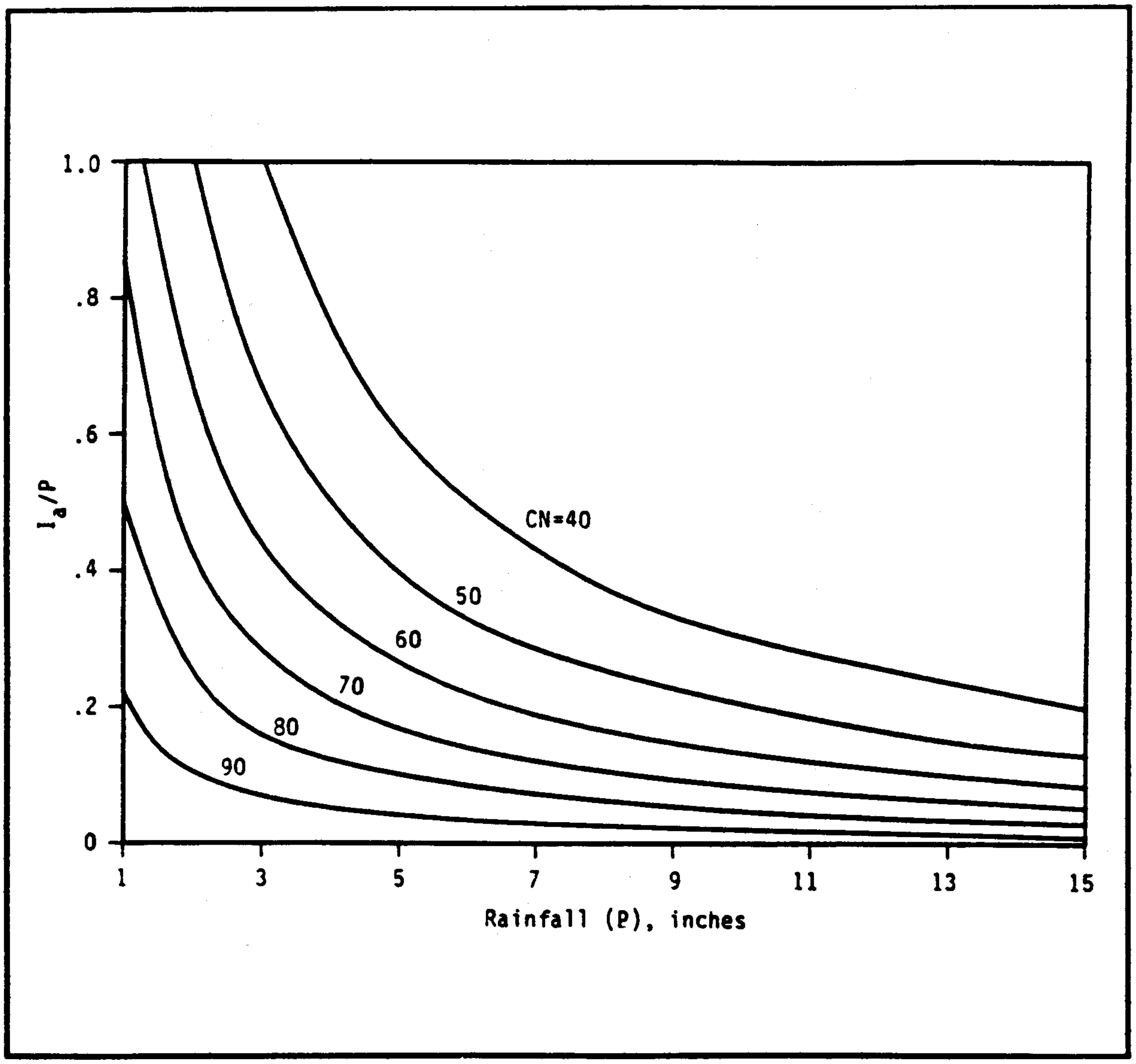


Table B-5 — I_a Values for Runoff Curve Numbers

Curve number	I_a (in)	Curve number	I_a (in)
40	3.000	70	0.857
41	2.878	71	0.817
42	2.762	72	0.778
43	2.651	73	0.740
44	2.545	74	0.703
45	2.444	75	0.667
46	2.348	76	0.632
47	2.255	77	0.597
48	2.167	78	0.564
49	2.082	79	0.532
50	2.000	80	0.500
51	1.922	81	0.469
52	1.846	82	0.439
53	1.774	83	0.410
54	1.704	84	0.381
55	1.637	85	0.353
56	1.571	86	0.326
57	1.509	87	0.299
58	1.448	88	0.273
59	1.390	89	0.247
60	1.333	90	0.222
61	1.279	91	0.198
62	1.226	92	0.174
63	1.175	93	0.151
64	1.125	94	0.128
65	1.077	95	0.105
66	1.030	96	0.083
67	0.985	97	0.062
68	0.941	98	0.041
69	0.899		

Table B—6 — Adjustment factor (F_p) for pond and swamp areas that are spread throughout the watershed	
Percentage of pond and swamp areas	F_p
0.0	1.00
0.2	0.97
1.0	0.87
3.0	0.75
5.0	0.72

Limitations: The Graphical method provides a determination of peak discharge only. If a hydrograph is needed or watershed subdivision is required, use the Tabular Hydrograph method in Technical Release #55. Use TR—20 if the watershed is very complex or a higher degree of accuracy is required.

The watershed must be hydrologically homogeneous, that is, describable by one CN. Land use, soils, and cover are distributed uniformly throughout the watershed.

The watershed may have only one main stream or, if more than one, the branches must have nearly equal T_c's.

The method cannot perform valley or reservoir routing.

The F_p factor can be applied only for ponds or swamps that are not in the T_c flow path.

Accuracy of peak discharge estimated by this method will be reduced if I_a/P values are used that are outside the range given in Figure B—16. The limiting I_a/P values are recommended for use.

This method should only be used if the weighted CN is greater than 40.

When this method is used to develop estimates of peak discharge for both present and developed conditions of a watershed, use the same procedure for estimating T_c.

T_c values with this method may range from 0.1 to 10 hours.

Example 6:
Compute the 25—year peak discharge for the 250—acre watershed described in Examples 2 and 5. Figure B—15 shows how Worksheet 4 is used to compute qp.